

BIG IDEAS:

- Organisms need energy to grow, survive and reproduce.
- Most organisms obtain energy through photosynthesis or by eating other organisms.
- Primary production is affected by temperature, moisture and nutrients.
- Food chains show a specific pathway of energy flow in a community.
- Food webs are complex illustrations of interconnected food chains.
- Some species affect a food web more than others.
- Energy pyramids simplify food webs by sorting organisms into trophic levels.
- Only about 5 to 20 percent of energy passes from one trophic level to the next.

EXPLORING THE **Nature** OF **ENERGY FLOW**

Life squishes out from every soggy corner of a wetland. Red-winged blackbirds whistle from bulrushes growing at the water's edge. A falcon swoops like a feathered missile toward a flock of feeding ducks. Atop a muskrat lodge, a water snake lies motionless, soaking in the sun's warm rays. Nearby, a marsh wren takes time out from foraging for insects to scold the snake. Tadpoles swirl in the shade of an arrowhead plant, avoiding deeper water where sunfish and bullheads lurk. A river otter swims sinuously by, ignoring the tadpoles—it's hunting bigger game. Bullfrogs bellow, bitterns croak and everywhere is the hum of insects.

Hectare for hectare, Missouri's wetlands rival any place on the planet in the amount of life they produce. Nearly half of Missouri's 3,200 plant species are associated with wetlands, and more than a third of Missouri's birds depend on wetlands for some part of their life cycle. Shallow wetland pools act as nurseries for the offspring of many species of reptiles, amphibians and fish. And, some of Missouri's most important furbearers—beavers, muskrats, mink and otters—depend on wetlands for food and shelter. When you compare Missouri's wetlands with other ecosystems, only tropical rainforests and coastal salt marshes produce more life per square meter.

Wetlands create and support so much life by turning a tremendous amount of sunlight into usable energy. Each flap of a dragonfly's wings, each millimeter of growth by a cattail leaf, each warble from the throat of a marsh wren—all require energy. Indeed, from birth to death, every organism in a wetland—or any ecosystem for that matter—uses energy to grow, survive and reproduce. To understand how wetlands create and support such a tremendous amount of life, we need to explore the nature of energy, how various organisms use it, and how it is transferred from one organism to another.

Organisms need energy to grow, survive and reproduce.

Energy. Environmentalists contend Americans use too much energy. Politicians argue our country doesn't produce enough energy. Puppies and toddlers are full of energy. A rock band's music might be high energy. Refrigerators and dishwashers are often advertised to be energy efficient. Exercise can increase your energy. Too much work can drain your energy. After reading this chapter, you might claim, "I can't go on. I just don't have the energy." We've all heard of energy. But, what is it and what does it have to do with ecology?

Technically, **energy** is the ability to do work.

It's easier, however, to think of energy as something that creates change. For example, it takes energy to change your car from standing still to moving. It takes energy to change your stovetop from cold to hot. It takes energy to change your classroom from dark to bright.

Energy comes in many different forms. Heat, light, sound and electricity are all forms of energy. Forms of energy can be sorted into two main categories: kinetic and potential. Energy in motion is called **kinetic energy**. The sound of your teacher talking is kinetic energy because the sound waves produced by his or her voice move through the air to your ears. Because light moves in waves, sunlight is kinetic energy, also. Heat, electricity and the movement of objects are other examples of kinetic energy. Stored energy is called **potential energy**. An easy way to remember the difference between kinetic and potential energy is that potential energy has the potential to move, but is not moving right now. The chemical energy stored in molecules, such as carbohydrates and fats, is potential energy. Because they can potentially move and do work, the water behind a dam and a stretched rubber band also contain potential energy.

Energy cannot be created or destroyed. The total amount of energy in the universe is constant. Energy can, however, change from one form into another. Although you have to recharge your cell phone periodically, the energy it uses doesn't disappear. The cell phone transforms the chemical energy stored in its batteries into electricity, light (on the keypad

Energy in motion, such as the light waves striking these leaves, is kinetic energy. Energy that is stored, such as the water behind this dam, is potential energy.

and display), heat, and electromagnetic waves (which carry your voice from the phone to a cell tower to the person you're calling). The amount of energy your cell phone uses is perfectly balanced by the amount of energy it sends out in the form of light, heat and electromagnetic waves.

What does this have to do with ecology? Everything an organism does requires energy. For example, growing new cells, maintaining body temperature, pumping blood through the body, and escaping from predators all require energy. And, just like your cell phone, organisms get the energy they need by transforming one form of energy into another.





Most of the mass of this gigantic bur oak was built molecule by molecule from water and carbon dioxide in the air. During photosynthesis, the tree used the sun's energy to transform these molecules into glucose. This glucose was used for energy or rearranged and combined with other molecules to form the building blocks that make up the leaves, roots, bark and other parts of the tree.

Most organisms obtain energy through photosynthesis or by eating other organisms.

Just south of Columbia, in the floodplain of the Missouri River, grows a gigantic bur oak. Like all bur oaks, this particular tree began its life as a tiny acorn no bigger than the end of your thumb. Between 300 and 400 years ago—before Missouri became a state, before the Lewis and Clark expedition, before the Declaration of Independence was signed—the acorn fell from its parent, landed in fertile soil, and started to grow. Every year that the bur oak grew, it became a little taller and added a little more wood to its trunk and branches. Today, the tree is one of the largest of its kind, with a height of over 20 meters, a trunk nearly 3 meters in diameter, and a weight of over 20 metric tons. Where did the tree get the raw materials to create so much mass?

Most of the mass of the tree comes from water and carbon dioxide in the atmosphere. The process that begins the transformation of water and carbon dioxide into wood, leaves and other tissues is known as **photosynthesis**. During photosynthesis, plants, algae and some bacteria harness the energy provided by sunlight to transform six molecules of carbon dioxide (CO_2) and six molecules of water (H_2O) into one molecule of the sugar glucose ($\text{C}_6\text{H}_{12}\text{O}_6$) and six molecules of oxygen (O_2). A chemist might write the transformation like this:



During this reaction, the energy from sunlight doesn't disappear. Instead, part of the energy is reflected back into the atmosphere, part is transformed into heat, and part is stored in the chemical bonds of the glucose molecule. In essence, photosynthesis changes the kinetic energy of sunlight into the potential energy of glucose.

Glucose is an important molecule. Rearranged and joined together, glucose molecules can be turned into carbohydrates, fats and cellulose. When combined with nitrogen and other elements, glucose can form proteins and nucleic acids, which form the tissues of plants and other photosynthetic organisms. Ecologists refer to this process and the resulting tissues as **primary production**.

Glucose also can be used as an energy source. Although only photosynthetic organisms can convert the energy in sunlight into chemical energy, virtually every organism—from plants to people—can use glucose for energy. During a process called **cellular respiration**, oxygen and glucose react to form carbon dioxide and water. When this happens, the potential energy stored in glucose is released. Organisms use the resulting kinetic energy for growth, survival and reproduction. Plants and other photosynthetic organisms are called **producers** because they take a form of energy that most organisms can't use (sunlight) and *produce* a form of energy that most organisms can use (glucose).

Primary production is affected by temperature, moisture and nutrients.

Studying primary production is important to ecologists because it gives a measure of how much energy is available to the organisms in a community. Ecologists also like to know how fast primary production occurs because this tells them how quickly sunlight can be converted into usable energy.

Primary production is measured in several ways. One commonly used measure is mass per area per unit of time. To figure this, ecologists gather all of the plants (and other primary producers) in a defined area (usually a square meter) that have grown in a set period of time (usually a year). The ecologists dry the plants to remove all the water from their tissues and then determine their mass. This gives an estimate of how much tissue was produced for a given time, in other words, the rate of primary production.

As Figure 6.1 shows, some ecosystems have higher rates of primary production than others. To figure out why, we need to consider what affects the growth of plants and other producers.

Light is important. Without light, photosynthesis cannot occur. For example, the middle of the ocean has low primary production. The deeper you go in the ocean, the less light there is available for photosynthesis. Ecosystems near the poles also have low primary production. At the equator, day and night are equal. As you move away from the equator, the period of day to night shifts based on the season. In the summer, Antarctica has a “night” that last for several months. This long period of darkness limits the amount of primary production that occurs there.

Temperature also is important. Like most chemical reactions, photosynthesis is influenced by temperature. Generally, photosynthesis proceeds slowly at low temperatures and increases (to a point) as temperatures go up. Most producers are adapted to photosynthesize at the average temperature of their ecosystem. Generally, though, photosynthesis occurs best from 16 to 38 degrees C. This explains why colder ecosystems have lower primary production.

Remember that in photosynthesis, the reactants are water and carbon dioxide. Because carbon dioxide is found in adequate supplies in both terrestrial and aquatic ecosystems, it rarely limits primary production. Water, however, can be scarce in some terrestrial ecosystems, for example deserts, tundras and prairies. Without enough water, photosynthesis cannot occur.

Producers, like all organisms, need more than just carbon dioxide, water and sunlight to grow. As stated earlier, glucose combines with other elements to form the building blocks of living cells. Some of the most important elements that glucose combines with include nitrogen and phosphorus. A lack of nitrogen and phosphorus can limit the growth of producers. In terrestrial ecosystems, temperature and water usually limit primary production. In aquatic ecosystems, temperatures are usually stable and water is plentiful. Therefore, in aquatic ecosystems, a lack of nitrogen or phosphorus is often what limits primary production.

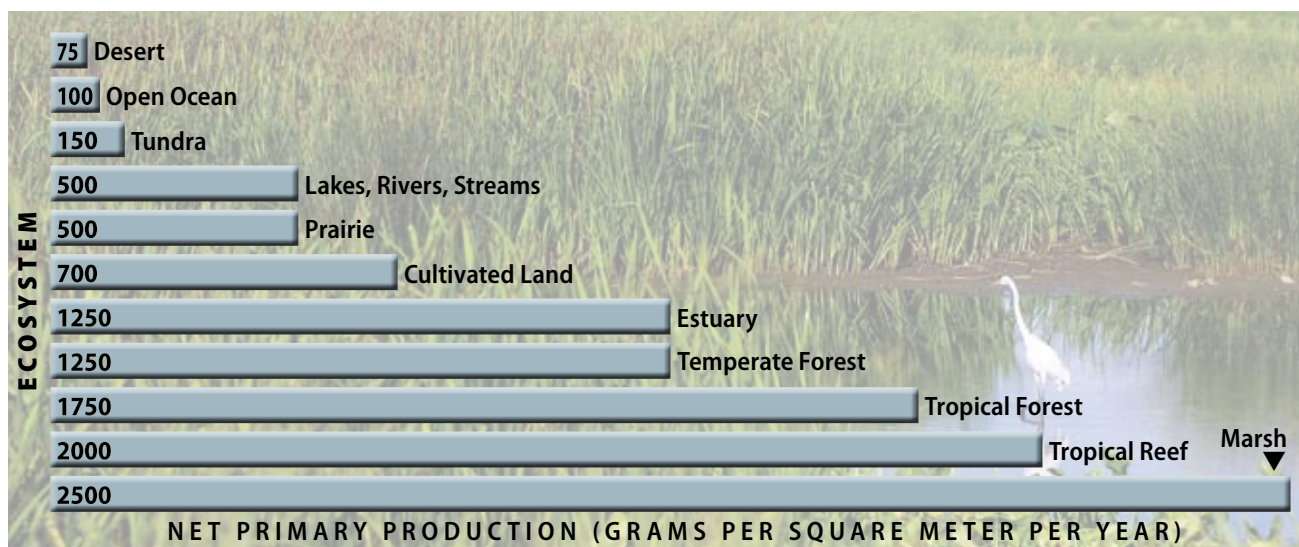


Figure 6.1—Primary Production of Various Ecosystems Measured in g/m²/year

Knowing what limits primary production can help us hypothesize why wetlands in Missouri contain so much life. By definition, wetlands are wet. So, water is unlikely to be a limiting factor. Missouri's marshes are relatively shallow—often 45 centimeters deep or less—and contain few trees. This allows producers at any depth and any location to receive plenty of sunlight. Because of its latitude, Missouri has longer days in the summer and longer nights in the winter, but this doesn't affect photosynthesis to a large degree. Therefore, we can hypothesize that light isn't a limiting factor, either. Most of Missouri's wetlands are associated with rivers. When the rivers flood, they overflow into wetlands, and deposit nutrients into the wetland soil. This process makes wetlands one of the most nutrient-rich ecosystems on the planet. Therefore, we can hypothesize that nutrients are unlikely to limit wetland primary production. Temperature limits primary production during Missouri's winter, but only for a few months. With these facts, we might hypothesize that wetlands are highly productive because few factors limit primary production. This would explain the enormous amount and variety of plants and other producers found in a wetland, but it doesn't explain all the other organisms that live there. To account for every bullhead, bullfrog and blackbird, we need to examine how energy flows through a wetland community.

Food chains show a specific pathway of energy flow in a community.

Energy flow is the transfer of energy from one organism to another. Because producers take a form of energy that most organisms can't use (sunlight) and convert it into a form of energy that most organisms can use (glucose), energy flow begins with producers. In a wetland, producers include cattails, sedges, bulrushes, smartweeds, arrowheads, algae, and many kinds of phytoplankton (a diverse group of tiny, often unicellular plants, protists and bacteria that live in water).

Organisms that cannot transform sunlight into usable energy must eat or consume other organisms to get energy. These types of organisms are called **consumers**. In a wetland, consumers include muskrats, ducks, fish, water snakes, river otters, mink and zooplankton (tiny aquatic animals and protists). Consumers can be divided into three groups based on what they eat:

- **Herbivores**, such as muskrats, eat plants and other producers.
- **Carnivores**, such as mink, eat other consumers.
- **Omnivores**, such as raccoons and humans, eat both producers and consumers.

Food chains show how energy is transferred from producers to different consumers. For example, Figure 6.2 is a food chain that shows how energy is transferred when algae, which are producers, are eaten by a pond snail, which is then eaten by a crayfish, and so on all the way up the food chain to the mink. Here are some other food chains that illustrate how energy is transferred when one organism eats another:

Algae→pond snail→bullfrog→northern water snake→great blue heron
 Arrowhead→blue-winged teal→northern harrier
 Arrowhead→muskrat→mink

Each food chain shows the specific pathway that energy from the sun takes as it is transformed by a producer and then incorporated into the tissues of different consumers. To draw all the pathways the sun's energy might take in a community, we would need to draw a food web.

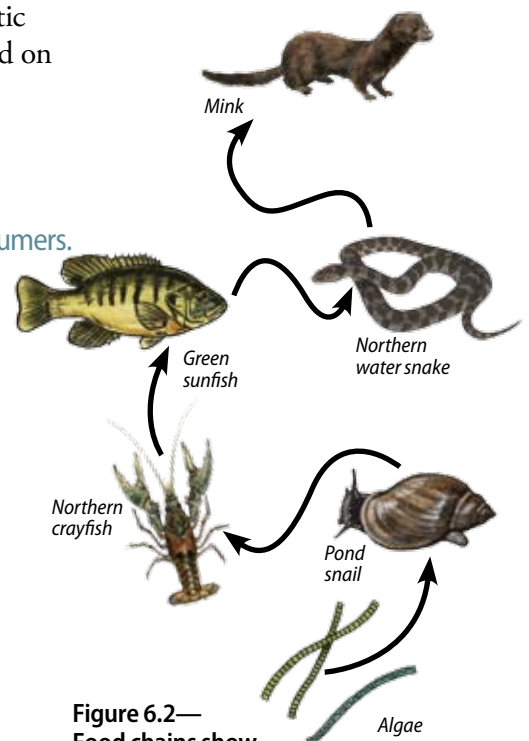


Figure 6.2—Food chains show how energy from the sun is transferred from a producer to various consumers. In this chain, energy flows from algae through several mid-level consumers to a mink.



Stocking Ponds

What does soil fertility have to do with stocking fish in a pond? Quite a bit, as it turns out. Fisheries biologists typically recommend stocking a combination of largemouth bass, bluegill and channel catfish fingerlings into a new pond. In locations where soil fertility is high, biologists prescribe 100 bass, 500 bluegill and 100 catfish for each half hectare of surface water in the pond. In areas with poor soil fertility, biologists recommend a ratio of 50 bass, 250 bluegill and 50 catfish. Why is there a difference in stocking rates?

It has to do with primary production. A pond's most important producers are microscopic plants called phytoplankton. Millions of these tiny plants give some pond water a greenish tint. Phytoplankton, like all producers, need more than carbon dioxide, water and sunlight to grow. They also require nutrients, such as nitrogen and phosphorus. These nutrients wash from the soil and dissolve in pond water. In areas with high soil fertility there are more nutrients available, and primary production by phytoplankton is higher.

Phytoplankton form the first link in a pond food chain. Phytoplankton are eaten by tiny animals called zooplankton. Aquatic insects, such as dragonfly, damselfly and mayfly larvae, feed on both zooplankton and phytoplankton. These insects are, in turn, eaten by fish.

Young bluegill survive on plankton and aquatic insects. When they get larger, bluegill add snails, small crayfish and small fish to their diet. In ponds, catfish do not play a significant role as predators. Instead, they feed on injured or dead fish and aquatic insects, crayfish and algae. At the top of the pond's food chain, bass eat bluegill, frogs, crayfish and other small animals. For each kilogram of bass produced in a pond, 3,676 kilograms of phytoplankton, zooplankton, insects and bluegill must be available in the pond's food chain.

Understanding how energy flows through a pond helps fisheries biologists fix common pond problems. Many ponds contain an overabundance of 20- to 30-centimeter long bass. Biologists call this a stockpiled bass population. The bass get just enough food to stay alive, but not enough to grow very large. They usually have long, skinny bodies, hollow bellies and disproportionately large heads. Many pond owners assume these

are young fish; however, they may be several years old. A stockpiled bass population can result from a number of things. The most common involves a pond where bass harvest is limited and bass reproduction is very good. Under these circumstances, bluegill, the primary prey of bass in ponds, cannot produce enough young to adequately feed the large numbers of bass. To solve the problem, biologists usually recommend increasing bass harvest by instituting a **slot length limit**. A slot limit is a special harvest tool in which fish under and over a certain length range can be harvested, but those that fall within a certain length range—the slot—have to be returned to the water. For stockpiled bass, anglers are encouraged to harvest fish less than 30 centimeters long, but to return to the water all fish between 30 and 40 centimeters. Bass longer than 40 centimeters may be harvested or released depending upon the angler's preference. Removing a large number of the smaller bass makes more food available to the remaining fish. In time, the remaining fish will grow larger, and the food chain will balance out.



A fisheries biologist stocks a lake with channel catfish.

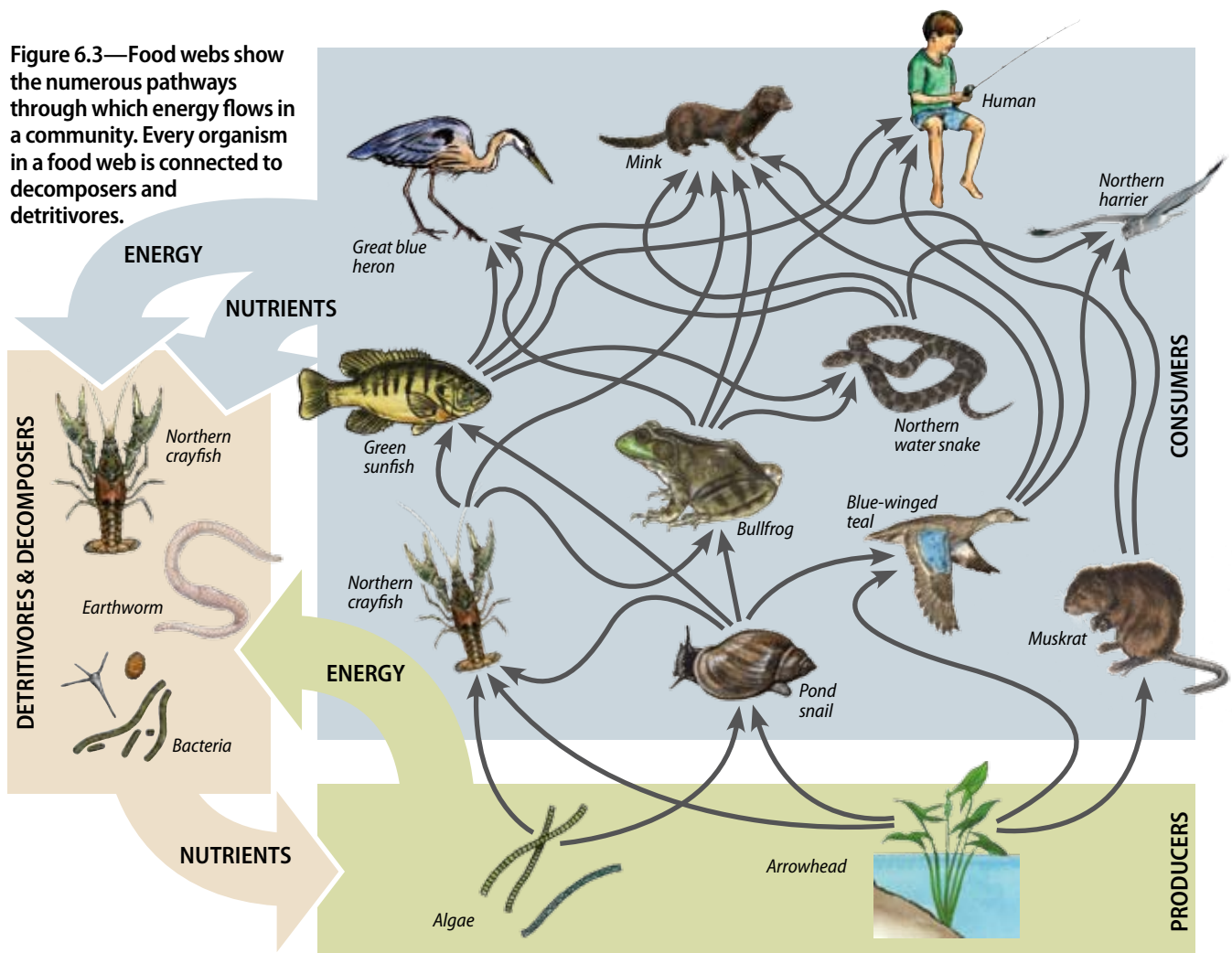
Food webs are complex illustrations of interconnected food chains.

Figure 6.3 takes the four food chains we talked about earlier and connects all the possible pathways energy could take as it is transferred from one organism to another. Ecologists call this kind of illustration a **food web**. Food webs show how food chains are interconnected. Ecologists use food webs to summarize energy flow in a community.

The food web shown below illustrates just a few of the millions of pathways through which energy flows in a wetland. Biologists have estimated that nearly half of Missouri's 3,200 plant species are associated with wetlands. Connecting the food chains associated with more than 1,500 producers and the thousands of consumers that eat them would make an extremely complicated food web!

Food webs become even more complex when we add in detritivores and decomposers. **Detritivores** are organisms that get their energy by feeding on dead organisms. By feeding on dead organisms and then excreting wastes, detritivores break down dead organisms into smaller pieces. Common detritivores in a wetland include crayfish, worms and many aquatic insects. **Decomposers** also feed on dead organisms, but they break the organisms down even further. Decomposers take the large molecules found in the tissues of an organism (such as carbohydrates, lipids and proteins) and break them down into simpler molecules (such as carbon dioxide, nitrogen and phosphorus). In doing so, decomposers create molecules that can be reused by producers during photosynthesis. Bacteria and fungi are often decomposers. Because every organism eventually dies, every organism in a food web can also be connected with one or more decomposers or detritivores.

Figure 6.3—Food webs show the numerous pathways through which energy flows in a community. Every organism in a food web is connected to decomposers and detritivores.





More species live in marshes that have muskrats than marshes that don't. By eating cattails, muskrats make room for other plants and animals. Since this increases the number of organisms in a marsh food web, muskrats are a keystone species.

By studying food webs, ecologists can make predictions on how the removal of one organism will impact other organisms in the community. For example, if all the algae suddenly disappeared from the wetland, not only would snails and crayfish be affected, but also the organisms that eat snails and crayfish, plus the organisms that eat those organisms, and every other food chain in the food web.

Some species affect a food web more than others.

In the same way that dandelions can quickly cover a lawn, cattails, if left unchecked, can quickly cover a shallow marsh. The consequences of this can be disastrous. Cattails can outcompete many other wetland plants for sunlight, space and nutrients. When these less-dominant wetland plants disappear, the organisms that use them for food or shelter disappear as well. Of course, the organisms that use wetland plants are themselves food for organisms higher on the food chain. In this way, a bumper crop of cattails can disrupt an entire wetland food web.

Enter the muskrat. Like a little rodent lawnmower, muskrats cut down cattails, bulrushes and other aquatic plants for food. They also use the plants to construct mound-shaped dens and feeding platforms throughout the marsh. Keeping a muskrat fed and housed requires a lot of plants. By removing many cattails from a wetland, muskrats allow less-dominant plants to gain a foothold. This creates a greater diversity of plants, which leads to a greater diversity of herbivores. A greater diversity of herbivores leads to a greater diversity of carnivores. By removing many of the cattails, muskrats also create areas of open water that can be used by species of waterfowl, fish and amphibians. So, just by reducing the dominance of cattails, muskrats have a staggering effect on the number of organisms in a wetland food web. Species like muskrats that affect a food web more so than other species are called **keystone species**.

It's important to avoid confusing keystone species with dominant species. A dominant species—like cattails or phytoplankton—may be one of the most abundant organisms in a community. Because of its abundance, dominant species usually have a strong influence over how energy flows through the community. In contrast, keystone species are usually one of the least abundant organisms in the community. However, despite their low numbers, they have a disproportionate effect on the way energy flows through the community.



Using a Keystone Lizard to Regrow Glades

Glades harbor some of Missouri's most interesting organisms. Nowhere else in the state can you find roadrunners, tarantulas, prickly pear cacti and collared lizards. Unfortunately, many glades in Missouri aren't very healthy. Overgrazing by livestock has destroyed many glades, and years of fire suppression has degraded others.

Without fire to keep trees in check, dense thickets of red cedars and post oaks invade glades, eventually shading out many of the sun-loving plants and animals that live there.

The Conservation Department, other government agencies and some private landowners are working to restore degraded glades in Missouri. Cedar-choked glades can be transformed back to open areas with an abundance of native plants and animals. All it takes is a little hard work.

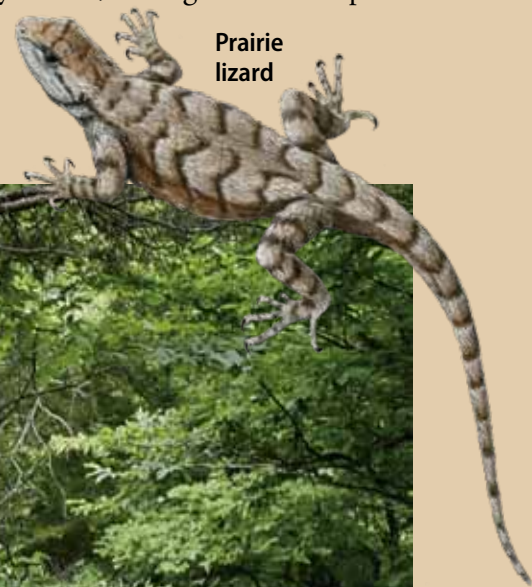
First the cedars and oaks have to be cut down. In the summer, this is sweaty, back-breaking work; in the winter, it's just back-breaking. Although some managers haul the cut trees to lumber mills, most stack them into brush piles. When the glade is burned, the brush piles burn up, too. This leaves a nice bare area for glade plants to regrow.

Glade plants have a tough time reestablishing if there are too many grasshoppers and other insects around. Grasshoppers can strip 10 to 80 percent of the foliage from glade plants in a single growing season. Although this doesn't usually kill the plants, it does lower the plants' reproduction, making it difficult for plant populations to increase.

Prairie lizards are voracious predators of grasshoppers. Prairie lizards, however, are homebodies and rarely venture far from shelter. They use boulders and brush piles as refuges from predators, places from which to ambush prey, and for shade to regulate their body temperature.

Peter Van Zandt and other researchers at Washington University in St. Louis found that glades might benefit if brush piles were left unburned. Van Zandt measured how far from shelter prairie lizards typically foraged. He also measured grasshopper densities and plant damage at various distances from brush piles. He found that over 85 percent of all lizards were observed within 1 meter of some kind of cover. As one might expect, grasshopper densities and plant damage increased at greater distances from cover.

Van Zandt's research suggests that if glade plants are being damaged by insects, leaving a few brush piles unburned might help. The brush piles will provide foraging bases for prairie lizards, which, in turn, will help reduce grasshopper numbers. With fewer grasshoppers, plants will have a better chance at reestablishing themselves in the hot and dry conditions of a glade.



In many ecosystems, the top predator in a food chain often acts as a keystone species. When white-tailed deer populations get too large, deer can strip the vegetation from an area. This is disastrous not only for the plants, but also for other organisms higher in the food chain. By harvesting deer, human hunters play the role of keystone predator once occupied by mountain lions and wolves. In doing so, hunters keep deer populations low, which keeps plant populations healthy. In turn, healthy plant populations support a much more complex food web.

Ecologists and resource managers find it important to identify the keystone species in an ecosystem. While each organism plays a role in the flow of energy and the functioning of an ecosystem, the loss of keystone species has a greater consequence than the loss of other, less influential species.

Energy pyramids simplify food webs by sorting organisms into trophic levels.

To simplify food webs, ecologists sort organisms into trophic levels. A **trophic level** is the position an organism occupies in a food chain. Knowing an organism's position in a food chain helps an ecologist predict what it might eat and what might eat it.

You're already familiar with one trophic level: producers. This trophic level contains all of the plants (such as cattails), phytoplankton, and other organisms in a particular community that use photosynthesis to convert sunlight into chemical energy. Because producers convert the sun's energy into other usable forms of energy, they make up the first trophic level.

Organisms that eat primary producers are grouped into a second trophic level: primary consumers. In a wetland, all of the herbivores, such as pond snails, fathead minnows and muskrats, would be grouped together as primary consumers.

The third trophic level is made up of secondary consumers that eat primary consumers. These organisms are primarily omnivores and carnivores, such as green sunfish, northern water snakes and bullfrogs.

The fourth trophic level is made up of tertiary consumers, such as mink and great blue herons, that eat secondary consumers. The fifth trophic level is made up of quaternary consumers, such as humans and other top level carnivores, that eat tertiary consumers. In this system each trophic level feeds on the one immediately below it.

Not every organism falls neatly into a single trophic level. Blue-winged teal migrate between breeding habitat in Canada and wintering habitat in the southern United States and Central America. On the way,

they stop in Missouri's wetlands to fuel up for their long flights. In the fall, blue-winged teal eat mainly seeds, which are high in carbohydrates and provide quick energy for a fast flight south. In the spring, however, blue-winged teal shift their diet to consume more aquatic invertebrates, which provide extra protein they need for reproduction. In the fall, blue-winged teal are mostly primary consumers, while in the spring they are mostly secondary consumers.

A mound of all the cattails, algae and other primary producers would tower over all the snails, minnows, blue-winged teal and other primary consumers. Likewise, a mound of primary consumers would make all the green sunfish,



Like many organisms, blue-winged teal can be placed in several trophic levels.

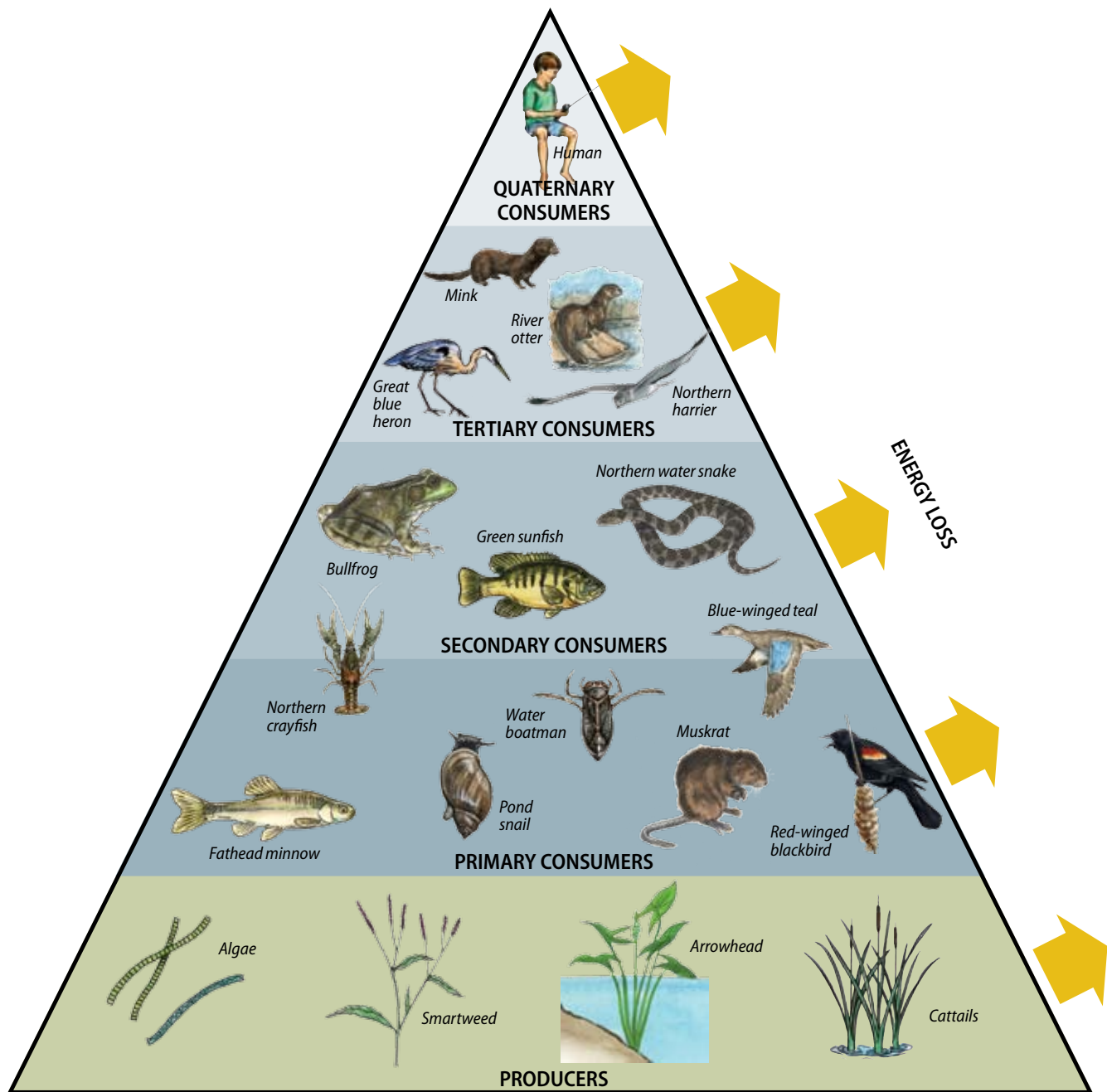


Figure 6.4—An energy pyramid's shape shows that consumers at higher trophic levels have less energy to support them than consumers at lower trophic levels.

northern water snakes and other secondary consumers look tiny in comparison. Moving from a lower trophic level to a higher trophic level, the combined mass of the organisms decreases. Because the mass of an organism is related to the amount of energy contained in the organism's tissues, ecologists use the mass of all the organisms in a trophic level to estimate how much energy is contained in that trophic level. When ecologists stack these energy estimates on top of each other with primary producers forming the base and going up through all of the consumers, the resulting graph forms a pyramid shape like Figure 6.4. **Energy pyramids** show how much energy is available at each trophic level.

In an energy pyramid, less energy is contained in each higher trophic level. We know that energy cannot be created or destroyed, so why does this happen, and where does the lost energy go? To answer these questions, we have to understand how organisms use the energy they consume.

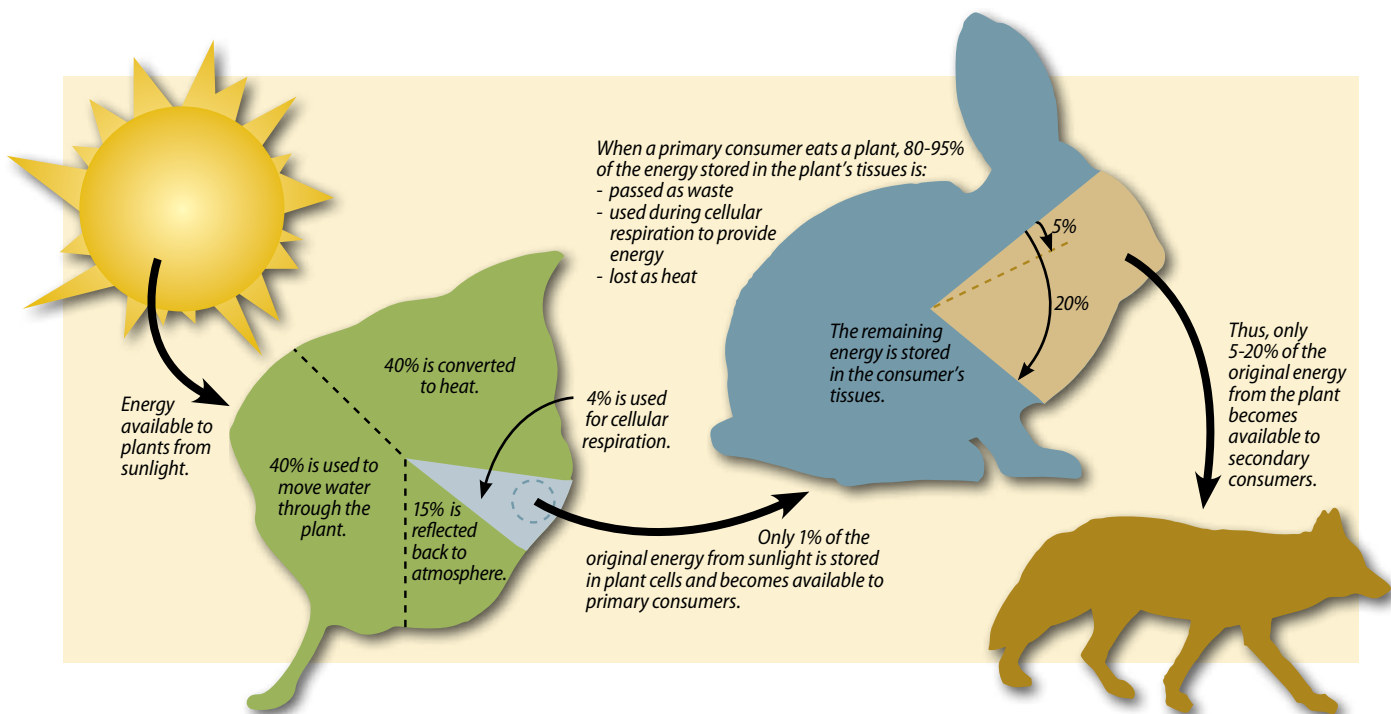


Figure 6.5—In general, only 5 to 20 percent of the energy in a trophic level passes to the one that follows.

Only about 5 to 20 percent of energy passes from one trophic level to the next.

Let's begin with plants. In general, of the energy available in sunlight, about 15 percent is reflected back into the atmosphere, 40 percent is converted to heat, and 40 percent is used to pull water from the ground through the roots to the leaves (*Figure 6.5*). This leaves only about 5 percent for photosynthesis. Plants use a portion of the energy converted by photosynthesis during cellular respiration, which fuels the processes that keep plants alive. The rest of the energy—about 1 percent—is stored in cells as the plant grows or produces offspring. This energy—about 1 percent of the total energy from sunlight—is available to primary consumers.

Primary consumers eat plants to gain energy, but not all of the plant is easily digested. Cellulose, lignin and certain other tissues often pass through the primary consumer's digestive tract and are excreted as waste. In this way, the energy contained in these tissues is lost to the primary consumer. Other organisms, such as detritivores and decomposers, can use the energy in this waste. Of the plant's tissues digested by the primary consumer, a large portion is used in cellular respiration to provide energy for processes, such as breathing, pumping blood and running from predators, that keep the primary consumer alive. These processes produce heat, which escapes into the air or water surrounding the organism. In this way, another large portion of the energy contained in the plant's tissues is used (in the case of cellular respiration) or transferred to the environment (in the case of heat). The rest of the energy in the plant's tissues is used to form new cells, which increase the size of the primary consumer or are used to produce offspring. This small fraction—between 5 to 20 percent of the original energy in the plant's tissues—becomes available to secondary consumers at the next trophic level.

The same thing continues at each higher trophic level. Secondary consumers cannot digest all of the bones, hair and teeth of the animals they consume, so some of this energy becomes fuel for decomposers instead of fuel for the consumer. Most of what is digested is used to keep the secondary consumer alive. Only a small fraction of the total energy gets stored in the secondary consumer's cells. Therefore, at each



In nearly every ecosystem, there always are more plants than herbivores, more herbivores than carnivores, and always just a few top-level predators such as this mink.

trophic level, 80 to 95 percent of the energy contained in the trophic level immediately below it is lost due to three things:

- The inability to digest certain tissues from organisms in a lower trophic level
- The use of energy to keep the organism alive
- The loss of energy as heat transferred to the environment

In general, only about 5 to 20 percent of the energy in a trophic level passes to the one immediately above it. This explains the triangular shape of energy pyramids. It also explains why most food chains have five or fewer links. Each time we move up a trophic level, there is less energy available. At some point, the energy runs out, and there isn't enough to support higher-level consumers. This is why in nearly every ecosystem there are always more plants than herbivores, more herbivores than carnivores, and always just a few top-level predators such as mink, herons and harriers. ▲



Atoms are recycled over and over again by living things. An atom forming the whisker of this deer mouse might have formed the toenail of a *Tyrannosaurus rex* millions of years ago.